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DEVELOPMENT OF AN ENFORCED STOP ALGORITHM FOR TRAIN APPLICATIONS

PHASE 1 RESULTS

prepared for

Transportation Development Centre
Policy and Coordination Group
Transport Canada

by

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Un sommaire en français de ce rapport est inclus avant la Table des matrières.

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16. Abstract

An enforced stop capability is a required component of level-30 Advanced Train Control Systems (ATCS) and will provide a major safety advance in railway signalling and control. This project is a first step in the development of a stop algorithm for a related application — a fixed-signal interface being developed by SignalCom Canada. This system will invoke a penalty brake application if a driver does not respond to a stop indication at a signal point in an existing Centralized Traffic Control (CTC) system. The structure of a conservative stop algorithm is outlined. There are three modules for the algorithm: a data input module; a stop distance preprocessor; and a real-time module which calculates the time to a penalty brake application and informs the driver. The algorithm demonstrates the same sensitivities when compared with the predictions of detailed simulation models for trains of known characteristics. It is recommended that more extensive validation tests of the algorithm be undertaken. There is a significant change in the development effort required to get an accurate stop controller rather than an enforced stop vigilance device such as this Phase 1 development represents. A second phase of development is required to incorporate learning (or an adaptive element) to the algorithm to get an accurate stop controller. As a first step in addressing both objectives of further validation of the existing algorithm and the inclusion of an adaptive element, it is recommended that event recorder data from a broad range of train types and track profiles be collected.

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16. Résumé

Les systèmes avancés de commande des trains (SACT) de niveau 30 comportent obligatoirement une fonction de freinage de sécurité et, à ce titre, ils représentent un progrès majeur sur le plan de la sûreté des installations de signalisation et de commande ferroviaires. Ce projet constitue la première étape du développement d'un algorithme de freinage destiné à une application connexe, soit celle de la surveillance de la conduite des trains au moyen d'un système d'interfaçage avec la signalisation ferroviaire latérale. Ce système commande l'application automatique des freins si le conducteur du train omet d'obtempérer à un signal d'arrêt affiché par un appareil de contrôle centralisé des trains (CCT). Ce rapport décrit l'architecture d'un algorithme de freinage "de sécurité". Celui-ci comporte trois modules, soit un module d'entrée des données, un préprocesseur des distances d'arrêt et un module de calcul et d'affichage en temps réel du délai de freinage de sécurité. L'algorithme donne des résultats comparables à ceux fournis par des modèles de simulation détaillée du comportement à l'égard de trains aux caractéristiques connues. L'effort de développement à consentir pour réaliser un contrôleur de freinage précis du type "arrêt au but" est sensiblement plus grand que s'il s'agissait de créer seulement un dispositif de veille et de freinage automatique de sécurité, objet de la phase I du project dont il est question ici. Pour réaliser le contrôleur de freinage précis envisagé, une deuxième phase de développement est nécessaire, visant à doter l'algorithme d'une fonction adaptative d'apprentissage. À titre de première étape vers la réalisation des deux objectifs suivantes, soit la validation plus poussée de l'algorithme existant et l'adjonction de la fonction adaptative d'apprentissage, il est recommandé de réunir des données d'enregistreurs-marqueurs d'événements concernant une gamme étendue de types de trains et de profils de voies.

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SUMMARY

An enforced stop capability is a required component of level-30 Advanced Train Control Systems (ATCS) and will provide a major safety advance in railway signalling and control. This project is a first step in the development of a stop algorithm for a related application — a fixed-signal interface being developed by SignalCom Canada. This system will invoke a penalty brake application if a driver does not respond to a stop indication at a signal point in an existing Centralized Traffic Control (CTC) system.

In this first phase of development, a conservative stop algorithm is developed and its results compared with the predictions of detailed simulation models for trains of known characteristics. It is recommended that more extensive validation tests of the algorithm be undertaken.

There are three modules for the brake algorithm: a data input module; a stop distance preprocessor; and a real-time module which calculates the time to a penalty brake application and informs the driver.

There is a significant change in the development effort required to get an accurate stop advisor rather than a enforced stop vigilance device such as this Phase 1 development represents. The fact that the Phase 1 controller's function is only t initiate an irreversible process, rather than make a controlled stop, simplifies the algorithm nd its associated hardware. However, it reduces the likelihood of making an accurate sto since there is no mechanism for further adjustments in brake level as the response is m nitored. If an accurate stop algorithm is desired, a second phase of development is requi d to incorporate learning (or an adaptive element) to the algorithm.

As a first step in addressing the objectives of fur er validation of the existing algorithm and the inclusion of an adaptive element, it is recomm nded that event recorder data from a broad range of train types and track profiles be collected In conjunction with the collection of these data, the parameter estimates required by the algor m would also have to be specified. These data would then serve as a data base for further velopment and testing.

SOMMAIRE

Les systèmes avancés de commande des trains (SACT) de niveau 30 comportent obligatoirement une fonction de freinage de sécurité et, à ce titre, ils représentent un progrès majeur sur le plan de la sûreté des installations de signalisation et de commande ferroviaires. Ce projet constitue la première étape du développement d'un algorithme de freinage destiné à une application connexe, soit celle de la surveillance de la conduite des trains au moyen d'un système d'interfaçage avec la signalisation ferroviaire latérale. Ce système commande l'application automatique des freins si le conducteur du train omet d'obtempérer à un signal d'arrêt affiché par un appareil de contrôle centralisé des trains (CCT).

Dans cette première étape, les chercheurs mettront au point un algorithme de freinage ordinaire, c'est-à-dire sans fonction d'arrêt au but, et en compareront les résultats aux prévisions de modèles de simulation détaillée concernant des trains aux caractéristiques connues. Cet algorithme comporte trois modules : un module d'entrée des données, un préprocesseur des distances d'arrêt et un module de calcul et d'affichage en temps réel du délai de freinage de sécurité.

L'effort de développement à consentir pour réaliser un contrôleur de freinage précis est sensiblement plus grand que s'il s'agissait de créer seulement un dispositif de veille et de freinage automatique de sécurité, objet de la phase I du projet dont il est question ici. Le fait que le contrôleur de freinage considéré dans la phase I a pour unique fonction d'enclencher un processus irréversible plutôt que de réaliser un arrêt au but, permet de faire appel à un algorithme et à un matériel informatique simplifiés. Par contre, la probabilité d'un arrêt précis au but est réduit du fait qu'aucun mécanisme n'est prévu pour moduler l'effort de freinage en fonction de la progression du train. Pour réaliser un contrôleur de freinage précis de type "arrêt au but", une deuxième phase de développement est nécessaire, visant à doter l'algorithme d'une fonction adaptative d'apprentissage.

À titre de première étape vers la réalisation des deux objectifs, soit la validation plus poussée de l'algorithme existant de l'adjonction de la fonction adaptative d'apprentissage, il est recommandé de réunir des données d'enregistreurs-marqueurs d'événements concernant une gamme étendue de types de trains et de profils de voies. Parallèlement, il y aurait lieu de spécifier les paramètres dont la valeur devra être connue par l'algorithme et qui constitueront la base de données nécessaire pour perfectionner et tester celui-ci.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. THE BRAKE ALGORITHM STRUCTURE 2
2.1 Data Input Module 2
2.2 Stop Distance Preprocessor 4
2.3 Real-time Penalty Brake Warning Module 7

3. VALIDATION TESTS OF THE ALGORITHM 9

4. CONCLUSIONS AND RECOMMENDATIONS 12

Appendix A: CN/SIGNALCOM CANADA ATCS SIMULATION CURVES

LIST OF TABLES

1. Assumptions on Typical Train Makeup 3

LIST OF FIGURES

1. Brake algorithm 2
2. Brake adhesion requirement 4
3. Stop distance control curves 5
4. Preprocessor 6
5. "Real time" module 7
6. Validation results - full-service stop, consist #1/+1% grade 9
7. Validation results - full-service stop, consist #1/0% grade 10
8. Validation results - stop algorithm curves - consist #1/-1% grade 10
9. "Real-time" module test results 11

1. INTRODUCTION

An enforced stop capability is a required component of level-30 ATCS and will provide a major safety advance in railway signalling and control. The minimum requirements to be considered in the development of an enforced braking algorithm have been specified by the ATCS committee.[1] The implementation of an automatic stop is not a trivial task. Even a rudimentary version of a braking algorithm requires relatively accurate information on the train, its location and the track profile. This information is not always accurately known. In addition, the available measures of train response (speed/acceleration) are restricted to one body of a multi-body system connected by elastic couplers. This presents significant problems to any form of on-board adaptation of parameters.

The objective of this first phase of development is to provide an algorithm which will locate a safe stop distance from any given boundary on a defined track profile, for a train of known characteristics.

The characteristics of this first phase controller have been largely influenced by a specific application — a fixed-signal interface being developed by SignalCom Canada. This system will invoke a penalty brake application if a driver does not respond to a stop indication at a signal point in an existing CTC system. In this application the brake controller need only consider a single transition strategy (i.e., penalty brake) and it need only consider a finite number of predefined stop locations (i.e., signal light positions). The fact that the controller's function is only to initiate an irreversible process, rather than make a controlled stop, simplifies the algorithm and its associated hardware. However, it reduces the likelihood of making an accurate stop since there is no mechanism for further adjustments in brake level as the response is monitored. What is feasible in this form of implementation is a conservative penalty brake actuator rather than an accurate stop controller.

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[1] ATCS Specification 311, *Predictive Enforcement Braking*, May 1989.

2. THE BRAKE ALGORITHM STRUCTURE

The algorithm is premised on the following:

- a driver may have been cycling the brakes as he approaches the stop point;
- if the engineman makes no attempt to apply brakes prior to the penalty enforcement, a conservative stop initiation is acceptable;
- if the engineman applies the brakes in an attempt to stop, the algorithm will, within limits, defer to the engineman's judgment.

The three principal modules of the brake algorithm are illustrated in Figure 1.

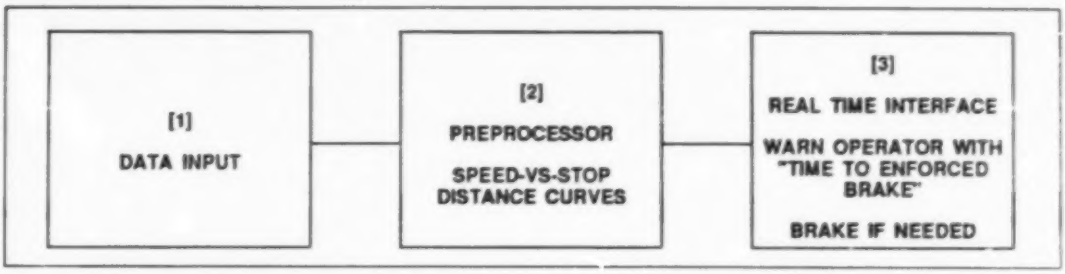


Figure 1 Brake algorithm

The first module involves data acknowledgment/input from the engineman. The second module is a preprocessor which generates, for each stop signal, a set of speed versus stop-distance curves corresponding to penalty actuation locations as a function of brake pipe pressure. These two activities are completed at the subdivision entrance point prior to departure. The final real-time module:

- monitors speed, location and brake pipe pressure;
- calculates the time to a penalty brake application; and
- informs the driver.

2.1 Data Input Module

The required data have been separated into two categories:

(1) data which is known and for which a direct numeric input can be made by the engineman; and

(2) data which may not be known and for which default values may be presented.

Those items falling into the first category are:

- ambient temperature;
- number of loco axles;
- number of cars;
- total train length;
- gross trailing weight;
- tare trailing weight;
- number of empties;
- number of cars with brakes cut out.

The ambient temperature is used in this model as a means of estimating brake pipe leakage. If the pressure gradient over the train length is known, or if the air flow rate at full charge is monitored they would provide a more accurate estimate. If the number of empties is not known, it is calculated from the gross-to-tare ratio assuming an average 60 ton load per car.

Those data which fall into the second category have been given the default values shown in Table 1. The operator may select the "train type" with its associated default values or may change individual parameters as warranted.

Table 1: Assumptions on Typical Train Makeup

	Brake Shoe Type	Car Capacity Distribution for NBR Calculations			Brake Settings			
Train Type	% Comp or HI-PH	Percent 100-ton	Percent 70-ton	Percen 50-ton	BPP	NBR	Aero Drag	ABDW Valves
Unit bulk	75	100	0	0	80	0.07	.07	N
Freight	20	10	70	20	72	0.08	.08	N
Passenger	100	100	0	0	90	0.20	.05	Y

In this Phase 1 development of the algorithm, the rake shoe type has only two classifications. The two friction-speed characteristics illustrated in Figure 2 are assumed for composition and cast iron brake shoes as indicated. The net brak ig ratio for cast iron shoes is assumed to 175% of those in Table 1 for composition shoes. Even with the higher braking ratio the cast iron shoes do not achieve stopping distances as sh rt as do the composition shoes. Thus, the inclusion of cast iron shoes is a conservative assu ption.

Composition shoes and high phosphorous cast iron shoes are assumed to produce the same braking performance. The AAR Mechanical Division *Manual of Standards and Recommended Practices* requires that high-phosphorous shoes achieve the same stopping distances as composition shoes (but at twice the net braking ratio needed with composition shoes).[2] Thus, the inherent assumption is that any high phosphorous equipped cars have twice the net braking ratio. A more accurate representation of high phosphorous shoes should be considered as one element of a Phase 2 program of development.

[2]Standards M 402 and M 926, *Manual of Standards and Recommended Practices* - Section E, Association of American Railroads, Operations and Maintenance Department, Mechanical Division.

Figure 2 also indicates the level of required friction between wheel and rail (i.e., adhesion). As the value is below 12% for most of the speed range, adhesion limitations were ignored in the algorithm.

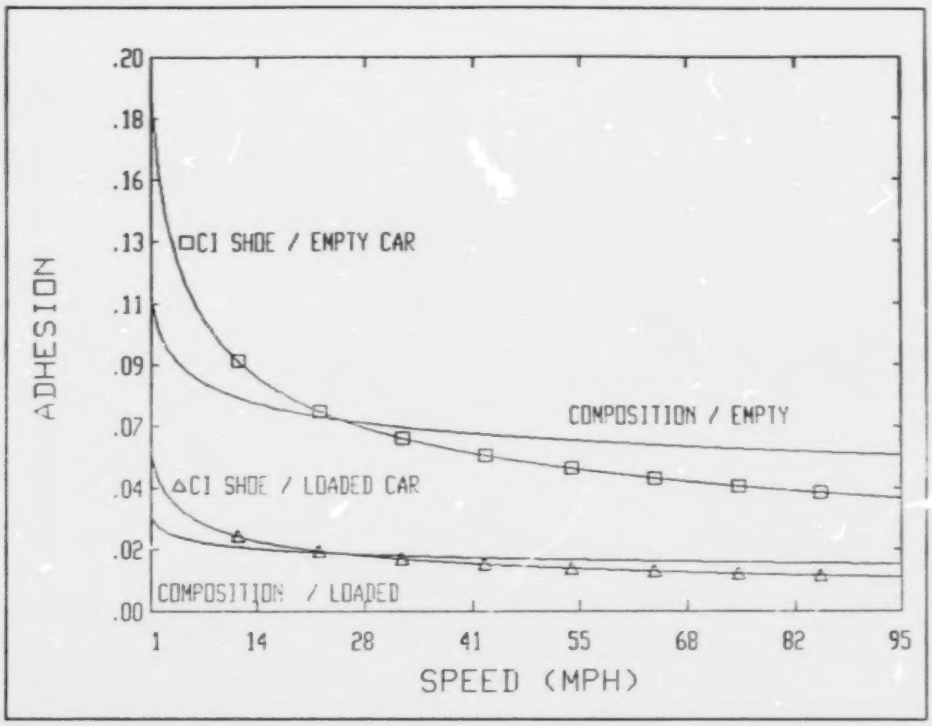


Figure 2 Brake adhesion requirement

The route data, which includes both profiles and stop locations, would be selected by name from a menu.

2.2 Stop Distance Preprocessor

The purpose of the preprocessor is to reduce the need for detailed calculations in real-time. The preprocessor produces a stop distance array which can be used with interpolation in real-time to predict the stop distance for actual conditions. Four speed-distance curves are generated for each stop location:

(1) an emergency stop curve;

(2) a steady-state, full-service application stop curve;

(3) a full-service brake application with air propagation delay, cylinder charging delays, and assuming nominal brake pipe pressure;

(4) the same conditions as in (3) but at reduced brake pipe pressure.

The curves are illustrated in Figure 3. The main components of the preprocessor are illustrated in Figure 4.

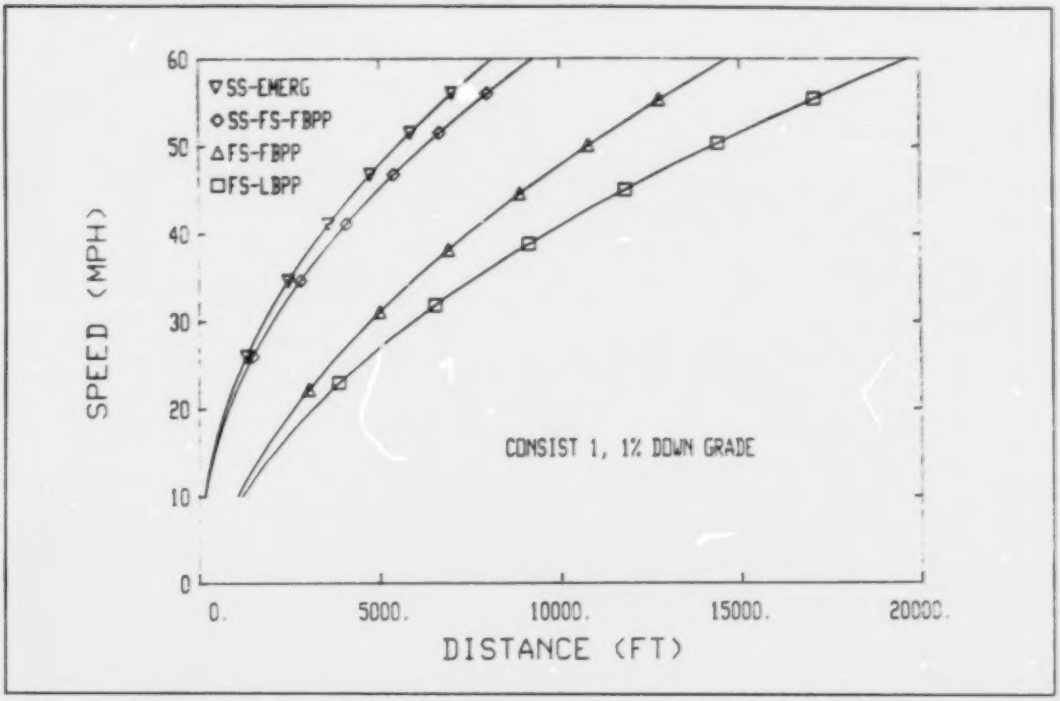


Figure 3 Stop distance control curves

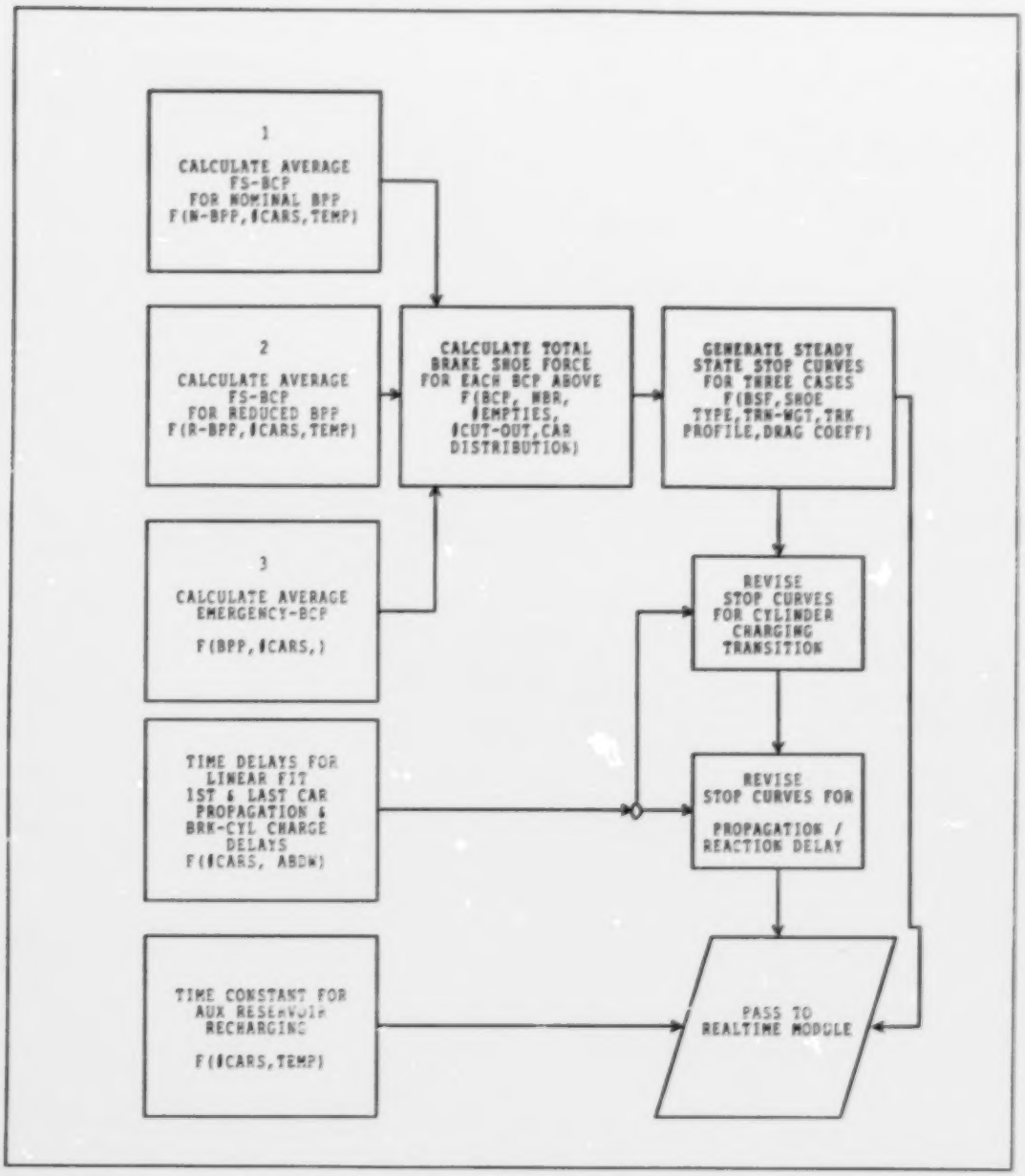

1
CALCULATE AVERAGE FS-BCP FOR NOMINAL BPP F(N-BPP,#CARS,TEMP)
2
CALCULATE AVERAGE FS-BCP FOR REDUCED BPP F(R-BPP,#CARS,TEMP)
3
CALCULATE AVERAGE EMERGENCY-BCP F(BPP,#CARS,)
TIME DELAYS FOR LINEAR FIT 1ST & LAST CAR PROPAGATION & BRK-CYL CHARGE DELAYS F(#CARS, ABDW)
TIME CONSTANT FOR AUX RESERVOIR RECHARGING F(#CARS,TEMP)
CALCULATE TOTAL BRAKE SHOE FORCE FOR EACH BCP ABOVE F(BCP, NBR, #EMPTIES, #CUT-OUT,CAR DISTRIBUTION)
GENERATE STEADY STATE STOP CURVES FOR THREE CASES F(BSF,SHOE TYPE,TRN-WGT,TRK PROFILE,DRAG COEFF)
REVISE STOP CURVES FOR CYLINDER CHARGING TRANSITION
REVISE STOP CURVES FOR PROPAGATION / REACTION DELAY
PASS TO REALTIME MODULE

Figure 4 Preprocessor

2.3 Real-time Penalty Brake Warning Module

The "real-time" module of the algorithm follows the logic outlined in Figure 5. It continually updates an estimate of the charge state of the brake system. On the basis of the state of charge, it interpolates between the "full-BPP" and "reduced-BPP" stop curves for the current train speed and calculates the time to reach that point. If the time is less than a minute, it is displayed for the engineman.

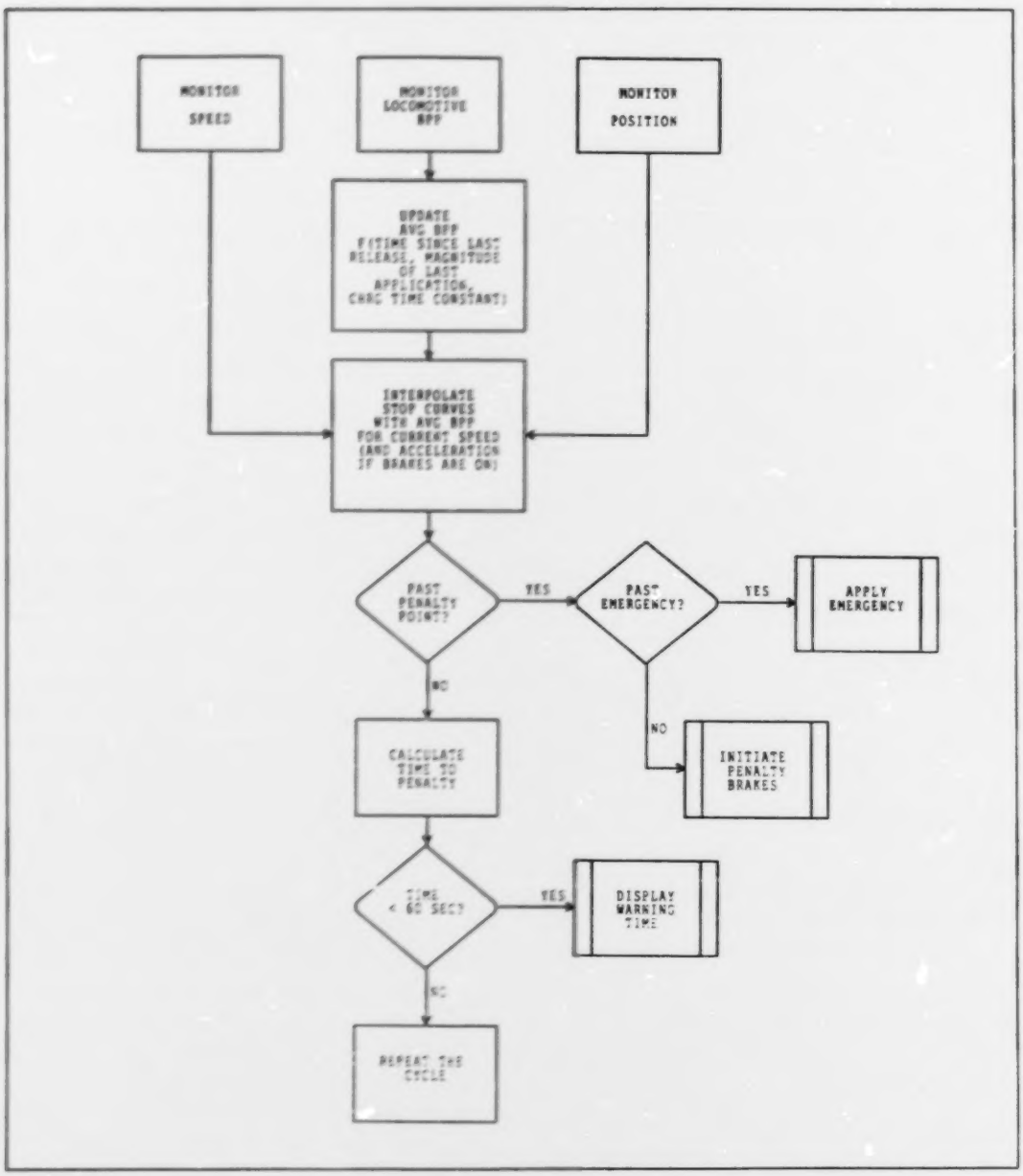


Figure 5 "Real time" module

If the engineman applies the air brakes prior to a forced penalty, the calculation is changed to consider the steady-state, full-service stop curve. The actual measured acceleration of the train is projected over the air brake propagation delay interval and the speed/position compared with the steady-state stop curve. A penalty application is made if it is crossed.

If a penalty application is invoked, the steady-state emergency brake curve is monitored in the same way the full-service curve was monitored above. If this curve is crossed, an emergency application is invoked. It should be noted that the only circumstance under which this may happen would be a situation where a brake release is made at such a point in the stopping manoeuvre that the brakes cannot be recharged to a sufficient pressure to make the stop under a full-service application.

3. VALIDATION TESTS OF THE ALGORITHM

The accuracy of the algorithm was tested in a comparison with two different simulation models:

- the Train Operations Simulator (TOS) developed by the AAR, and
- Canadian National Railway's stop simulator.

A range of stop distance curves were generated by CN's Transportation Planning Department with their simulation model (Appendix A). Stop distance-versus-speed curves were produced in the algorithm preprocessor for these same train/profile combinations and some were simulated with TOS. The results for the number 1 consist are illustrated in Figures 6, 7 and 8. In general, the algorithm results were close to the two simulation model outputs with deviations to the conservative side (i.e., longer stop distances). There was a spread between the two simulation model results which gets larger at low speeds.

The real-time component of the model was tested via an interface with the TOS model. A train was started in the automatic mode with a "maintain speed" instruction. As the train approached the stop curves (generated by the preprocessor), the warning time was displayed on the monitor. Once the train crossed the penalty brake decision point, a full-service brake application was invoked. In the limited number of test runs made, the simulator brought the train from a 50-60 mph speed range to a stop in a range of 20 to 700 feet in front of the target point.

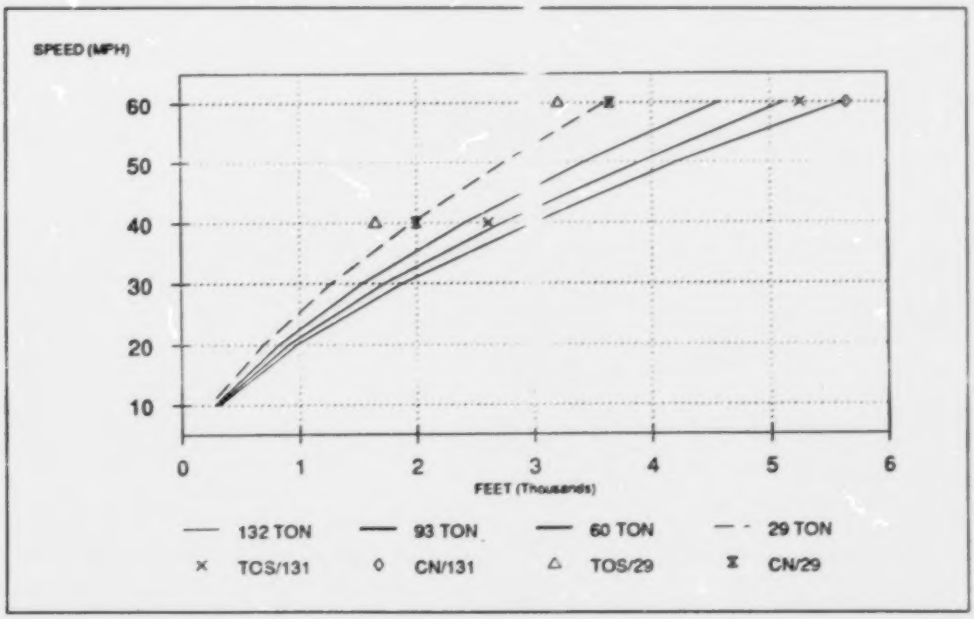


Figure 6 Validation results - full stop service - consist #1/+1% grade

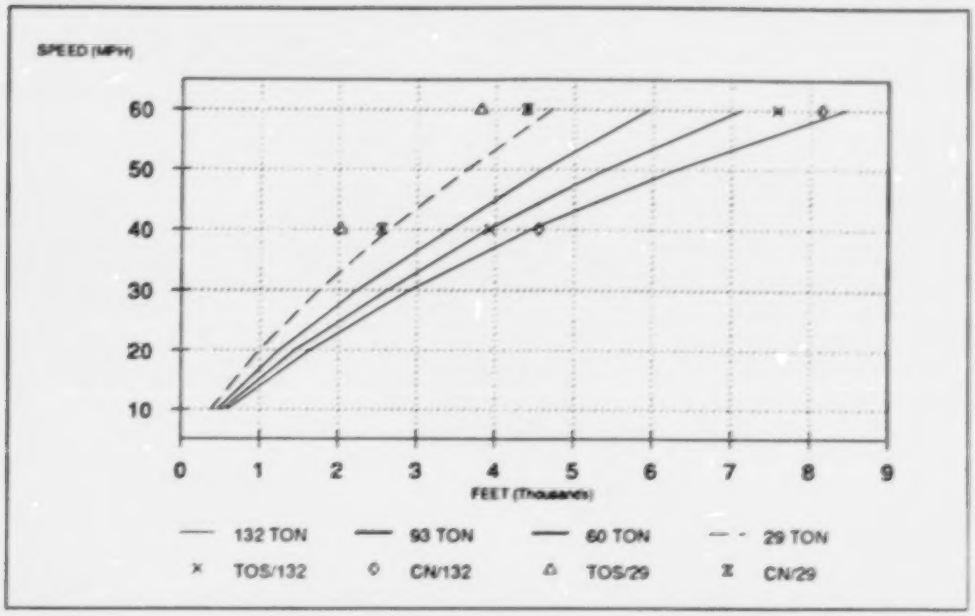


Figure 7 Validation results - full-service stop, consist #1/0% grade

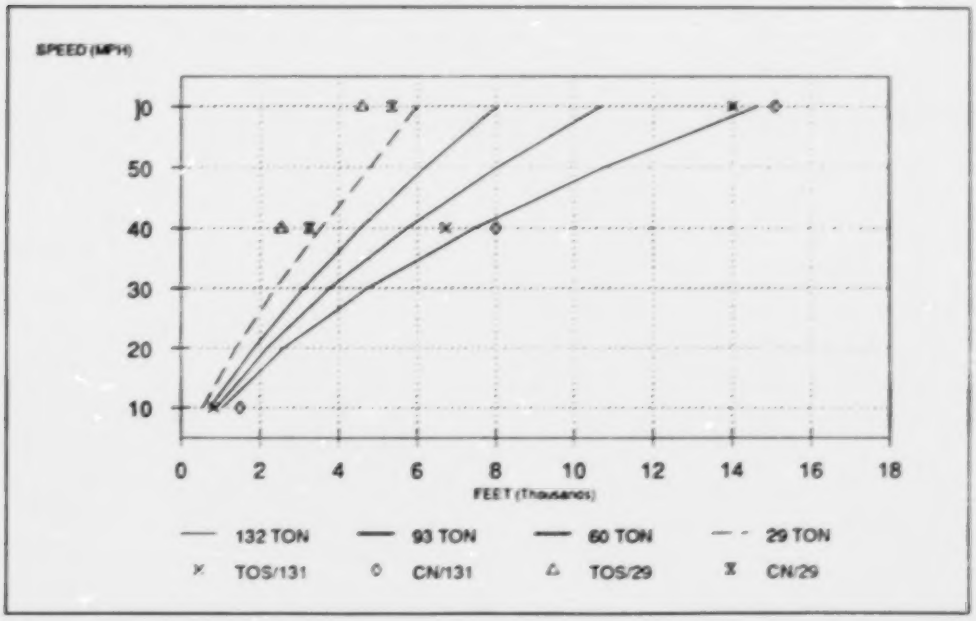


Figure 8 Validation results - stop algorithm curves - consist #1/-1% grade

The real-time module was also tested in a normal stop situation where a partial brake application was made in the penalty warning interval. Figure 9 illustrates the results. A 10 lb reduction was made well ahead of the stop location, bringing the train from 43 mph down to 31 mph. The brakes were released and the train coasted from that point until the next application. A one-minute warning was given at mile 8.8. At mile 9.25 the warning time was 50 seconds and a second 10 pound reduction was initiated by the engineman and maintained. The penalty warning time fluctuated around 30 seconds for the remainder of the stop manoeuvre.

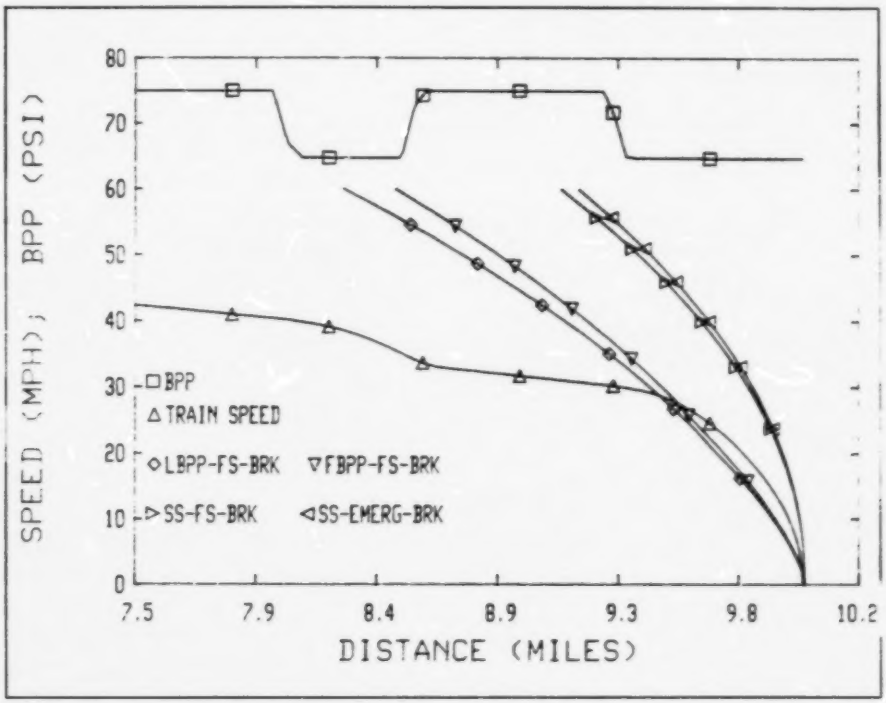


Figure 9 "Real-time" module test results

4. CONCLUSIONS AND RECOMMENDATIONS

A penalty brake algorithm has been developed and a set of conservative data estimates developed. In limited comparison with other simulation models where the data are known, the algorithm demonstrates similar stop distance sensitivities.

However, it is important to undertake more extensive validation tests of the model. Also, the influence of some of the simplifying assumptions needs to be checked in more detail. Of particular interest would be tests of the following simplifications:

- a detailed friction characteristic for high-phosphorous brake shoes is not incorporated;
- temperature effects on friction are not detailed in the algorithm;
- the transition phase of brake cylinder pressure build up is linearized.

It is also important to finalize guidelines of any stop enforcement system as a first step of further development. There is a significant change in the development effort required to get an accurate stop advisor rather than an enforced stop vigilance device such as this Phase 1 development represents.

As noted earlier in this report the fact that the Phase 1 controller's function is only to initiate an irreversible process, rather than make a controlled stop, simplifies the algorithm and its associated hardware. However, it reduces the likelihood of making an accurate stop since there is no mechanism for further adjustments in brake level as the response is monitored.

If the device is used only as a vigilance device of last resort, a conservative set of parameter estimates will not interfere with normal operation. A short stop will not be expected to happen very often since the engineman will normally respond to the warning with a partial service application in stopping. Only if no action is taken will the penalty brake application be applied. If the engineman does respond in the warning interval, the algorithm adopts less conservative assumptions in deference to the engineman's judgment.

This approach would be unacceptable if the engineman tries to interpret the warning as advice on when he should apply a full-service application. If an accurate stop algorithm is desired, a second phase of development is required to incorporate learning (or an adaptive element) to the algorithm. Two approaches are possible:

(a) adapt the internal representation of the required train characteristics on the basis of locomotive speed measurements during the journey; or

(b) adjust the magnitude of airbrake application in relation to the train response during the forced stop.

The first approach would integrate well with the existing penalty brake initiation scheme but the latter would be much more accurate since the feedback from which the algorithm must learn is much more relevant and up-to-date.

As a first step in addressing both of the objectives of further validation of the existing algorithm and the inclusion of an adaptive element, it is recommended that event recorder data from a broad range of train types and track profiles be collected. In conjunction with the collection of these data, the parameter estimates required by the algorithm would also have to be specified. These data would then serve as a data base for further development and testing.

APPEND X A

CN/SIGNALCOM CANADA AT 'S SIMULATION CURVES

CN

Internal Correspondence

Correspondance Interservice

Department, place and date/Service, lieu et date: Transportation — Montreal, Que. 1988 05 06

Your file/Votre dossier: and letter dated/et votre lettre datée du:

Our file/Notre dossier: TP 5075-50

Subject/Objet: Stopping Distance Curves - ATCS

Mr. W. J. Moore Ede
Manager - Advanced Train Control
7 Desauville
Mart D, Place Bonaventure
Montreal, Que.

As per your request, a number of simulations were conducted using the Detailed Braking Distance program to produce a family of full service stopping curves for the CN/Signalcom Canada ATCS test project.

Attached are nine graphs containing the results of full service stopping tests conducted on three train consists at three different grades (-1%, level, +1%). Each graph contains the speed vs. stopping distance curves for a particular consist on one of the three grades. The results are provided for 3 or 4 different weight/car scenarios.

The three consists simulated were:

Consist 1:

3 GP30 locomotives (weight 194.5 tons, length 65.7 ft.)
90 cars (weight 152 tons (fully loaded), length 59 ft.)

Consist 2:

2 GP30 locomotives (weight 194.5 tons, length 65.7 ft.)
70 cars (weight 90 tons (fully loaded), length 59 ft.)

Consist 3:

1 GP30 locomotive (weight 194.5 tons, length 65.7 ft.)
30 cars (weight 71 tons (fully loaded), length 59 ft.)

Please note that the following assumptions were used in the simulations:

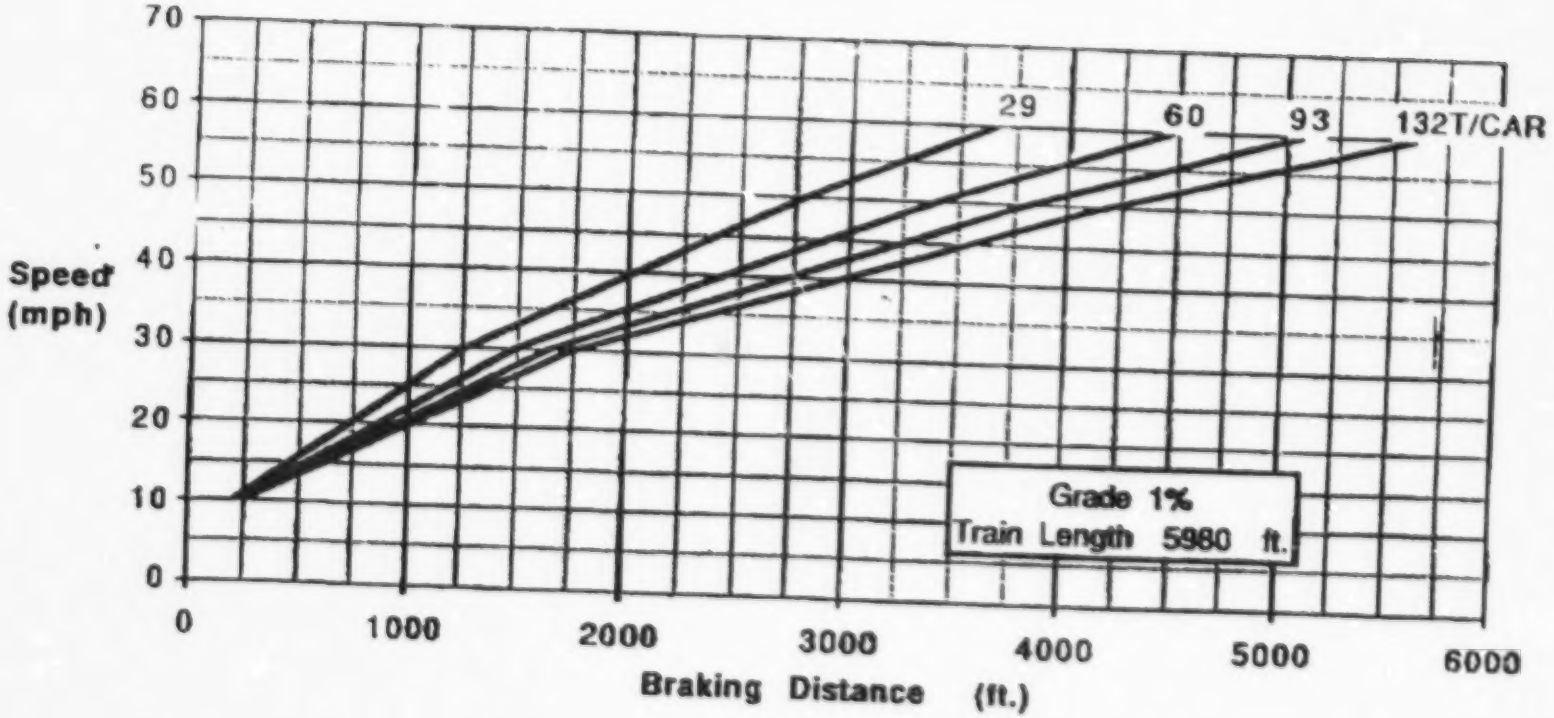
1. All stops were simulated with the locomotive brakes bailed.
2. All simulations were based on 75 psi brake pipe pressure, 2 psi/min. leakage and a 40° F. ambient temperature.
3. All cars had a Net Brake Ratio of 0.65 (AAR minimum) and composition brake shoes.

J. F. R. Gussow
System Transportation Engineer

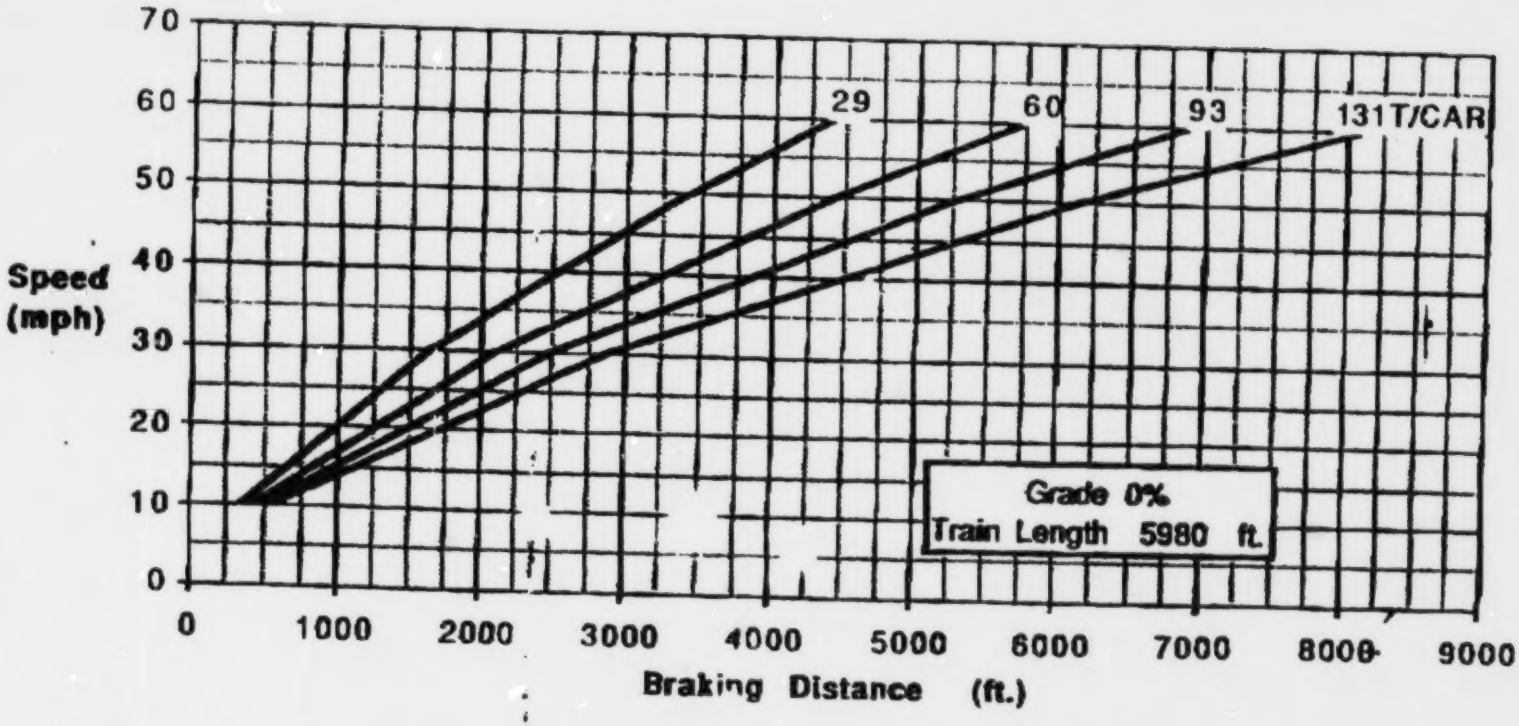
Attach.

DEW46/GW

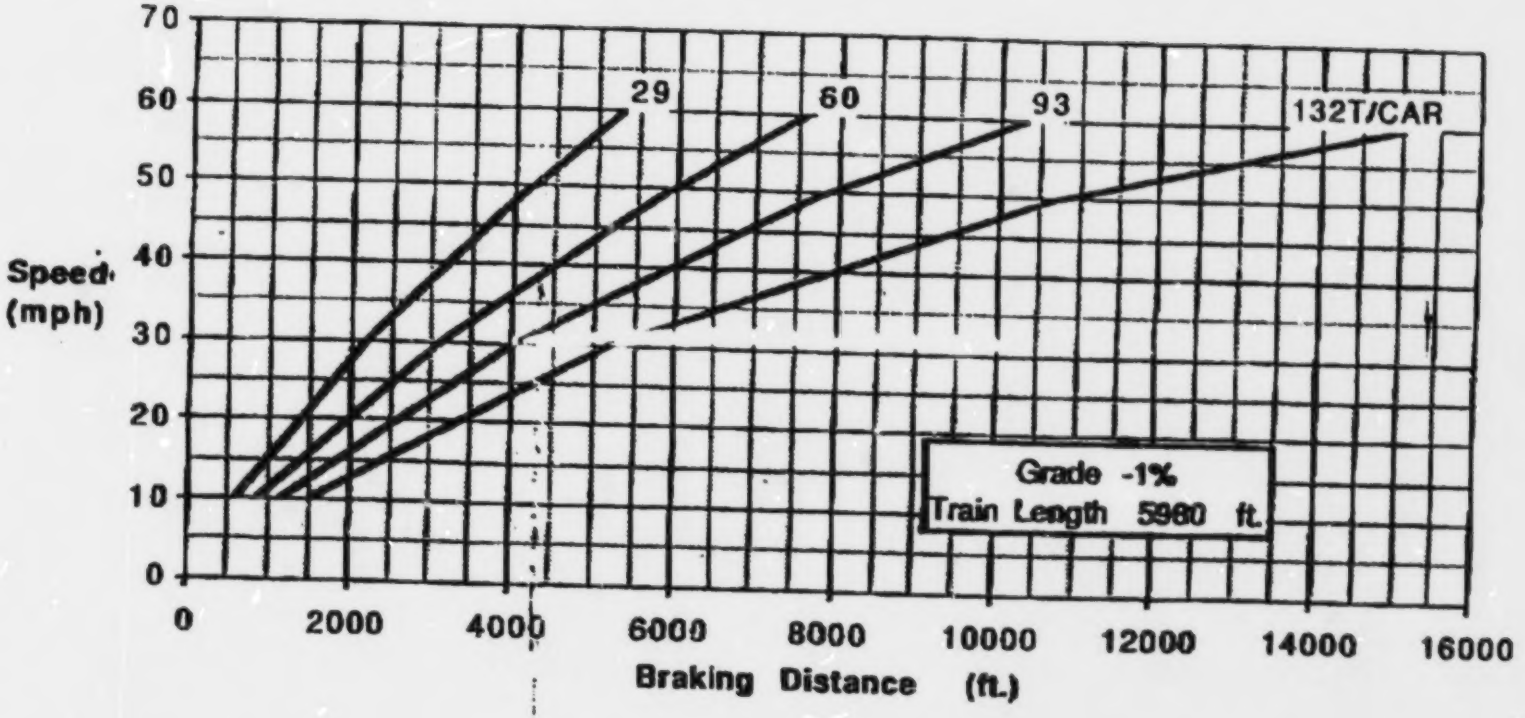
FULL SERVICE STOPS - CONSIST #1
3 GF30's + 98 cars (132T fully loaded wt.)

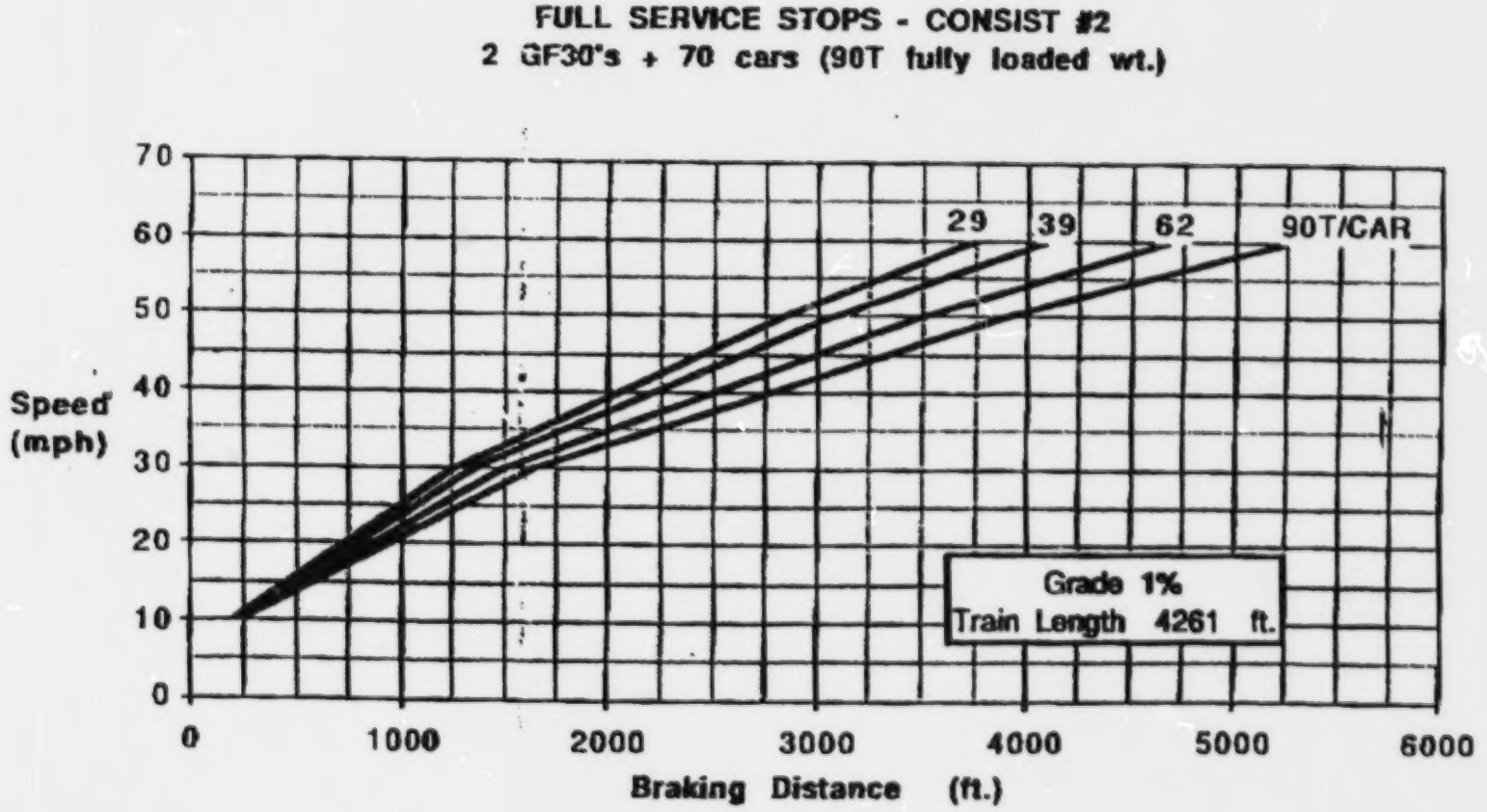


FULL SERVICE STOPS - CONSIST #1
3 GF30's + 98 cars (132T fully loaded wt.)

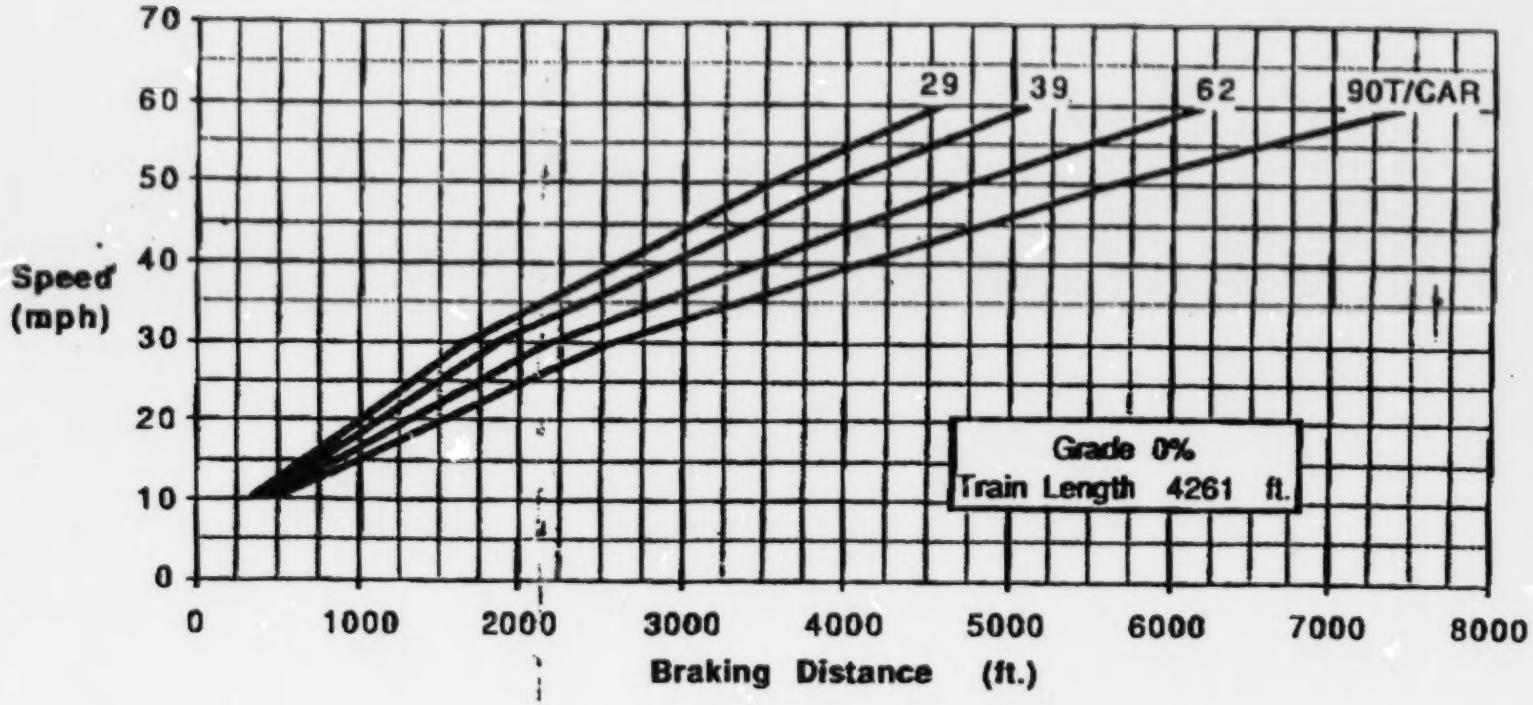


FULL SERVICE STOPS - CONSIST #1
3 GF30's + 98 cars (132T fully loaded wt.)

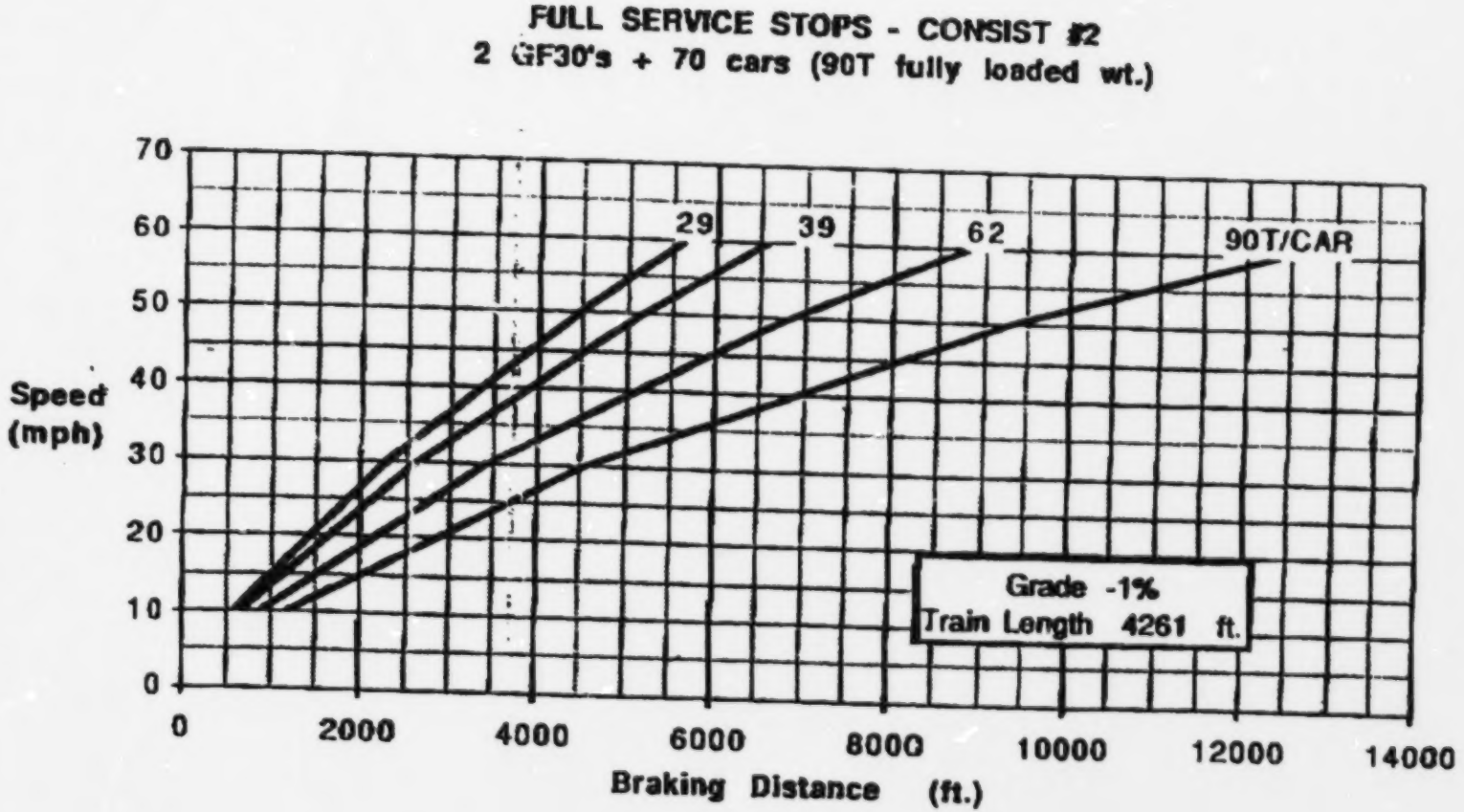


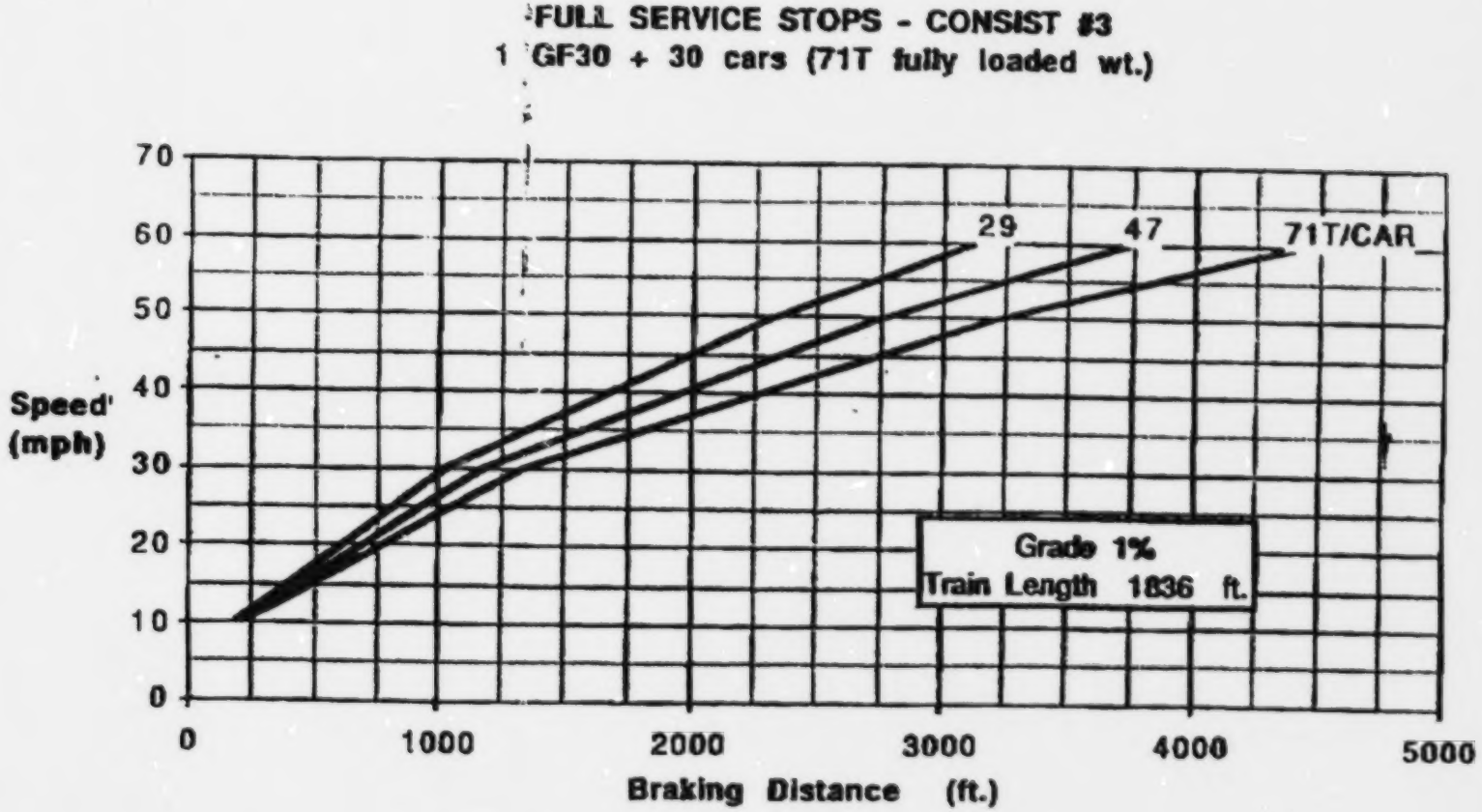

FULL SERVICE STOPS - CONSIST #2
2 GF30's + 70 cars (90T fully loaded wt.)
Speed (mph)
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
Braking Distance (ft.)
29
39
62
90T/CAR
Grade 1%
Train Length 4261 ft.

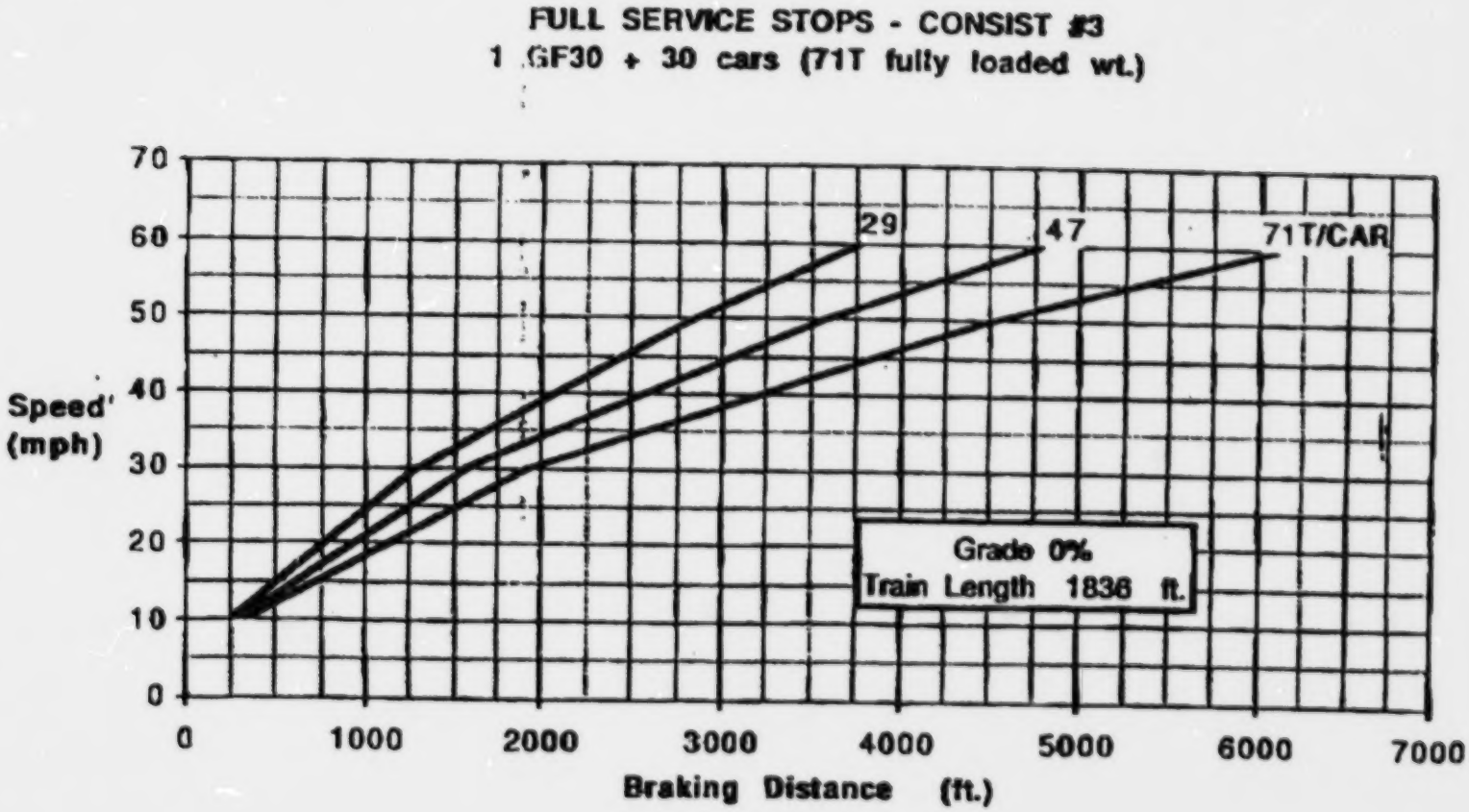
FULL SERVICE STOPS - CONSIST #2
2 GF30's + 70 cars (90T fully loaded wt.)

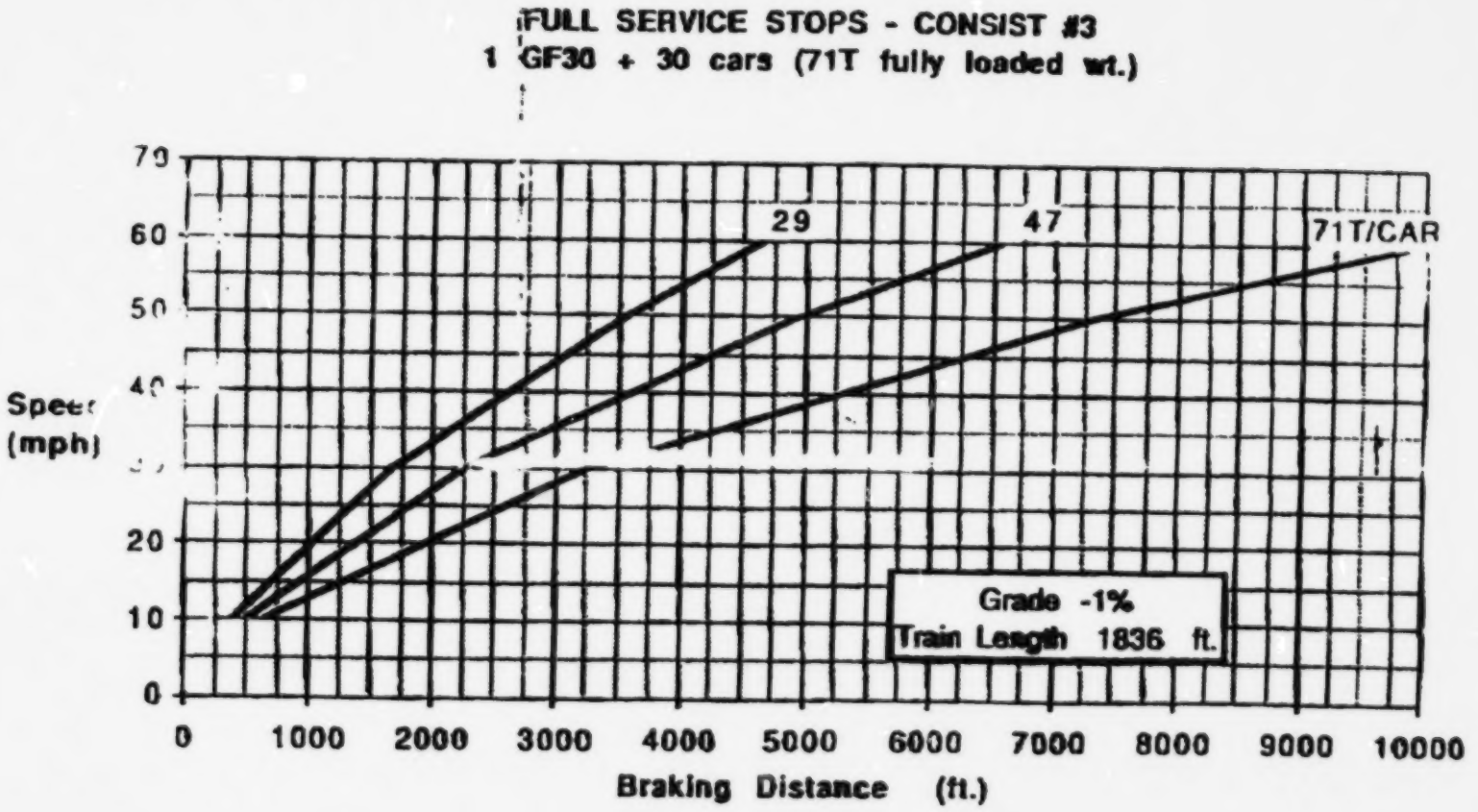


A.7


FULL SERVICE STOPS - CONSIST #2
2 GF30's + 70 cars (90T fully loaded wt.)
70
60
50
40
30
20
10
0
Speed (mph)
29
39
62
90T/CAR
Grade -1%
Train Length 4261 ft.
0
2000
4000
6000
8000
10000
12000
14000
Braking Distance (ft.)


FULL SERVICE STOPS - CONSIST #3
1 GF30 + 30 cars (71T fully loaded wt.)
70
60
50
40
30
20
10
0
Speed (mph)
29
47
71T/CAR
Grade 1%
Train Length 1836 ft.
0
1000
2000
3000
4000
5000
Braking Distance (ft.)


FULL SERVICE STOPS - CONSIST #3
1 GF30 + 30 cars (71T fully loaded wt.)
Speed (mph)
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
7000
Braking Distance (ft.)
29
47
71T/CAR
Grade 0%
Train Length 1836 ft.


FULL SERVICE STOPS - CONSIST #3
1 GF30 + 30 cars (71T fully loaded wt.)
70
60
50
40
20
10
0
Speed (mph)
29
47
71T/CAR
Grade -1%
Train Length 1836 ft.
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Braking Distance (ft.)